# THE EFFECT OF SMALL CONCENTRATIONS OF CARBON IMPURITY ON DISLOCATION MOBILITY IN IRON MONOCRYSTALS*

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## Introduction

Experiments have recently been reported by Turner and Vreeland (1) in which the dislocation velocities in pure iron single crystals were measured. This paper describes some limited results for identical experiments on crystals containing approximately 45 ppm by weight, of carbon. These results indicate that the carbon has very little effect on the velocity of free dislocations. However strong pinning effects were observed for aged dislocations.

## Experimental Procedure

Test specimens were prepared from the same parent crystal used in the earlier experiments. Sample preparation prior to carburization was the same as previously reported (1). The finished specimens were carburized by heating them to 800°C for 16 hr in a sealed quartz capsule containing an atmosphere of hydrogen and acetylene containing $C^{14}$. The carburization process is described more fully by Stein and Low (2).

Since the test specimens were too small to be accurately analyzed for carbon concentration, the radio activity of the samples was to be used to determine the carbon concentration. In order to establish the relationship between counting rate and the carbon concentration a larger piece of pure polycrystaline iron was included in the quartz capsule during carburization. This piece was large enough to provide several samples for chemical analysis. When the single crystal which provided the test specimens was grown by the strain anneal technique, the end of the sheet from which it was suspended remained polycrystaline. This portion of the material had undergone the same purification treatment as the single crystal to which it was attached. This portion of the sheet was chosen for the polycrystaline control standard for analysis because its initial composition, before carburization, was expected to be nearly the same as that of the test specimens.

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* This work was supported by the US Atomic Energy Commission.

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After carburization, the samples and the standard were removed from the quartz capsule and their activities were measured. For purposes of the measurement the specimens were held a standardized distance from a Geiger tube and a lead mask was placed over the sample so that only a fixed area of the sample surface was exposed to the tube. Since only comparative values of the activity are important, it is only necessary that conditions be the same for all samples and for the standard. By measuring the activity of the sample then polishing it and then remeasuring the activity, it was found that the surface had a higher carbon concentration than the bulk of the material. This effect was expected as it has previously been reported by Stein and Low (2). Therefore the activity measurement, polishing, activity measurement sequence was continued until it was determined that the high carbon concentration layer had been removed. The polishing solution used was 15 parts 30% $H_2O_2$, 15 parts $H_2O$ to one part 50% HF, and polishing intervals ranged from 30-60 sec. The polycrystaline standard was polished more than the samples since it was important for an accurate calibration that its composition be homogeneous. Test specimens were given a final electropolish in $Cr_2O_3$, Acetic Acid solution as described elsewhere (1). Final counting rates for the samples tested and for the standard are given in Table 1.

The standard was analyzed for carbon at the US Steel Corporation Edgar C. Bain Laboratory. The results are given in Table 1. Assuming the mixture of $C^{12}$ and $C^{14}$ to be the same in both the samples and the standard, the carbon concentration of the test samples can be calculated from the relative activities. Calculated concentrations for the two specimens in which dislocation motion was observed are given in the Table. It should be noted that since the counting rates for the sample and the standard were small and of similar magnitude, errors arising from the dead time of the counter should be relatively unimportant. The major sources of the uncertainty of the concentration are the scatter in the measured rates and the uncertainty of the chemical analysis.

The details of the testing procedure are described elsewhere (1), so the procedure will only be summarized here. Dislocations were created in the samples by scratching their surfaces with a glass knife edge loaded with about 1 gm wt. The dislocation configuration which consisted of slip bands moving on planes nearly parallel to the specimen surface was recorded by Berg-Barrett x-ray topography. The specimens were bonded with epoxy resin into a torsion bar. The torsion bar was subjected to a constant moment for a short duration. The sample was removed from the torsion bar and the resulting dislocation configuration was recorded by Berg-Barrett topography. An important aspect of the process is that the bonding of the test arrangement required curing the epoxy at a temperature of 150°C for one hour or at room temperature for 48 hours. Tests were carried out at room temperature and at 198°K.

## Results

The dislocations produced by the scratching did not move significantly in any of the tests. No dislocation motion during the test was discernible at stresses below approximately 200 Mdyn/$cm^2$. At stress levels above 200 Mdyn/$cm^2$ slip bands were found on the samples. Generally these slip bands originated from an identifiable surface source such as a small pit which would act to increase the local stress. For the two specimens which exhibited dislocation motion, the dislocation displacements were converted into average velocities by dividing by the pulse duration. These values of stress and velocity are shown in Fig. 1 along with the line representing the data

for pure crystals. The data lies within the scatter bands of the data for the pure crystals at the two temperatures for which motion was observed.

From this limited data it appears that at this low concentration, the carbon impurity affects dislocation motion only if it is allowed to collect to form atmospheres at the dislocation Therefore the effect of the carbon is to limit the initial free dislocation density. However after a sufficient stress is reached that fresh dislocations are generated their motion is little influenced by the carbon atoms. It would therefore appear that the rate limiting process for dislocation motion in both the pure crystals (1) and those used in this study is the same and that it is not hardening by interstitial impurities.

TABLE 1.

Carbon Concentration of Specimens

POLYCRYSTALINE SAMPLE

| | |
|---|---|
| Counting Rate: | 1114 ± 41 counts/min. |
| Carbon Concentration: (by analysis) | 58 ± 10 wt. ppm |

TEST SPECIMENS

| No. | Test Temperature (°K) | Counting Rate (counts/min) | Computed C Concentration (wt. ppm) |
|---|---|---|---|
| C-2 | 295 | 811 ± 20 | 42 ± 11 |
| C-5 | 198 | 901 ± 16 | 46 ± 11 |

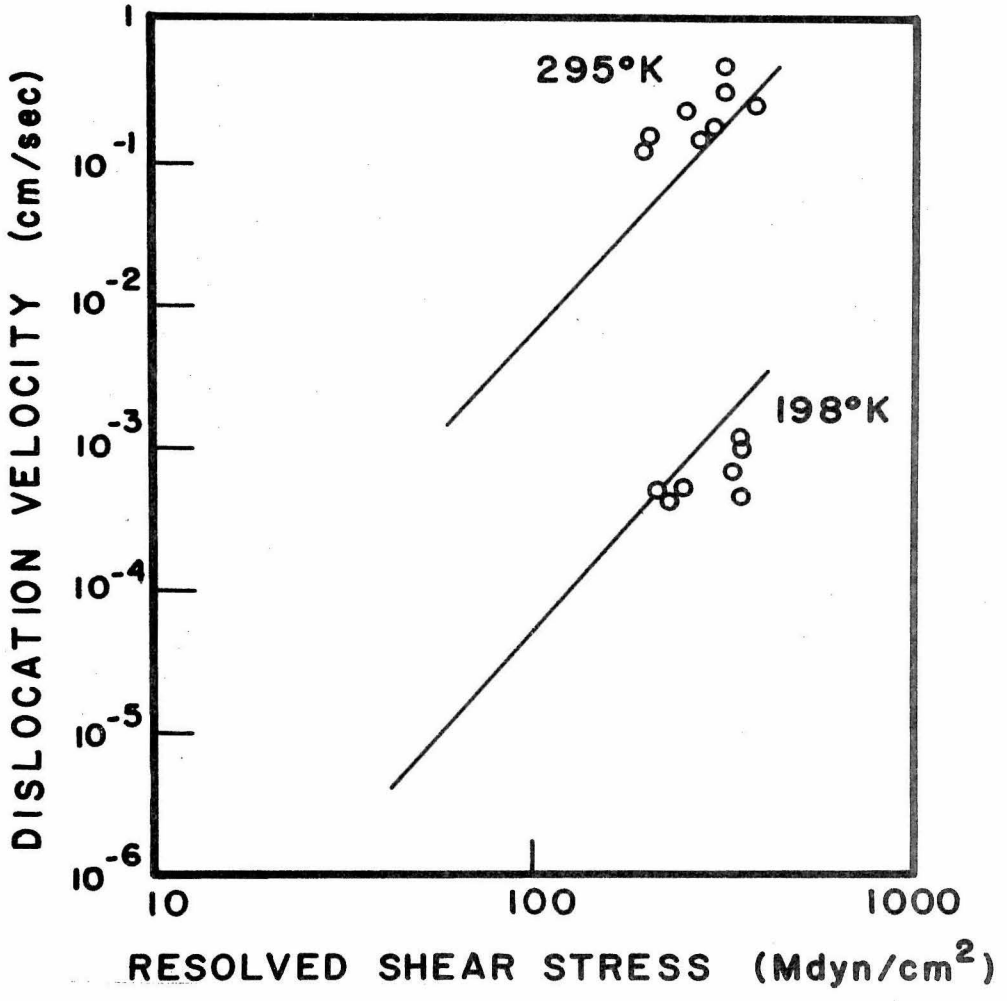
Acknowledgment

The authors would like to thank Dr. I. M. Bernstein of the Edgar C. Bain Laboratory of US Steel who arranged for the chemical analysis of the standard sample.

References

1. A. P. L. Turner and T. Vreeland, Jr., Acta Met., to be published.
2. D. F. Stein and J. R. Low, Jr., Acta Met. 14, 1183 (1966).

Fig. 1.




Velocity of edge dislocations in iron single crystals containing approximately 45 ppm carbon by weight. Solid lines represent mean of previous measurements on pure crystals.